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Starch to protein ratios in practical diets for genetically improved farmed Nile tilapia *Oreochromis niloticus*: Effects on growth, body composition, peripheral glucose metabolism and glucose tolerance

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饲粮中不同的淀粉与蛋白质比例：对吉富罗非鱼生长、机体组成、外周葡萄糖代谢和葡萄糖耐量的影响

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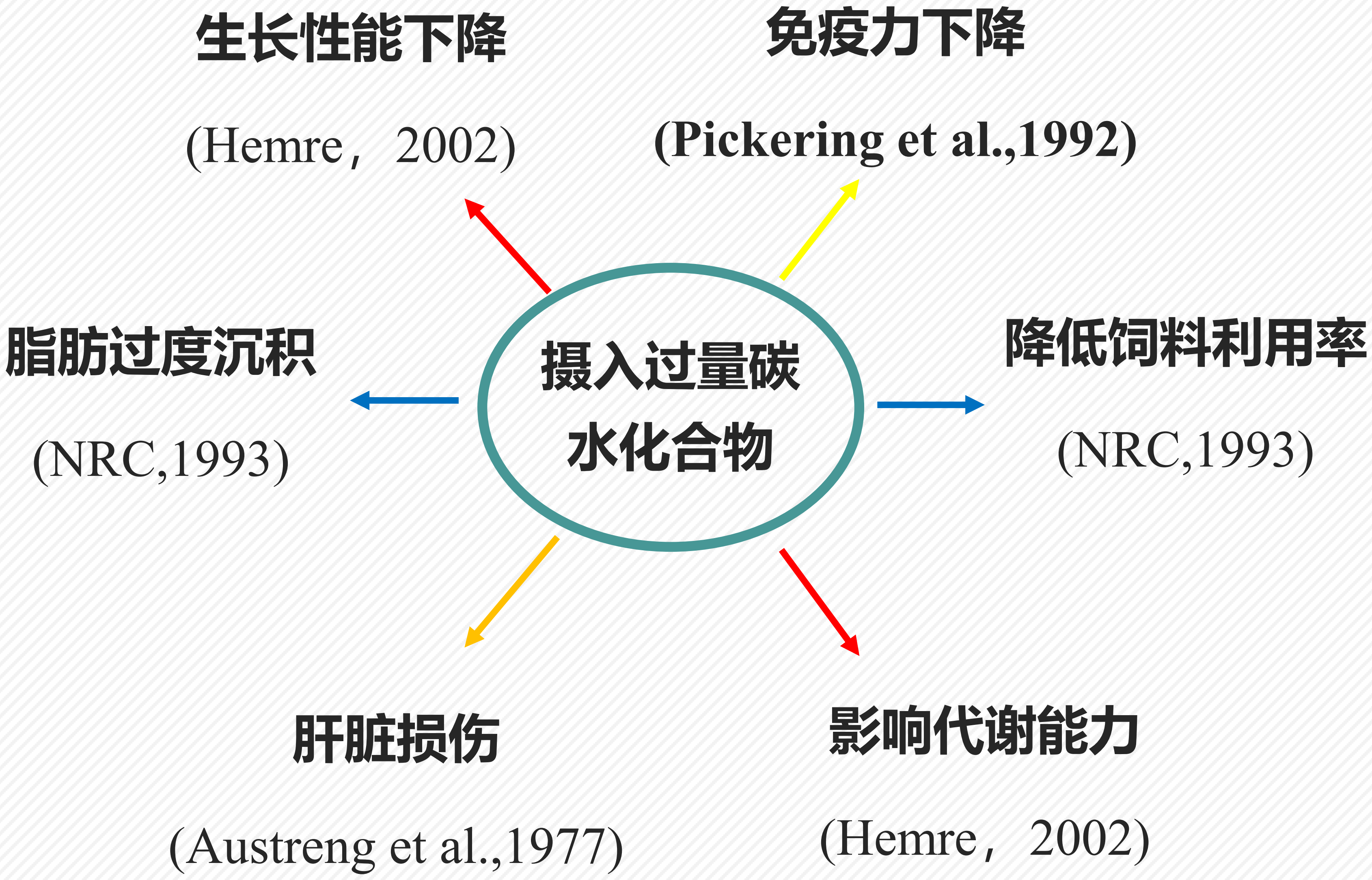
1 研究背景

1 研究背景

蛋白质 对于鱼类维持生长和繁殖是必不可少的，但过量的蛋白质，则会导致氮排泄量增加等问题，并且蛋白质是水产饲料中最昂贵的宏量营养素，造成饲料成本增加。

碳水化合物 和脂质等替代能源可满足能源需求并减少饲料中蛋白质的含量（Kaushik和Seiliez，2010；NRC，2011））。**碳水化合物**是成本最低的能源，它的加入可提高蛋白质的利用和保留能力，并在许多鱼类中可起到节约蛋白质的作用。

1 研究背景



因此，当使用碳水化合物减少饲料中蛋白质的含量时，蛋白质与碳水化合物的比例必须保持在明确定义的范围内。

1 研究背景

鱼类利用碳水化合物的效率取决于它们的摄食习惯

草食性和杂食性鱼类

40-50%的膳食碳水化合物

肉食性鱼类

碳水化合物上限建议为20%

（NRC，2011 ; Polakof et al.，2012 ; Kamalam et al.，2017）

1 研究背景

吉富罗非鱼

◆ 在杂食性鱼类中，罗非鱼是仅次于鲤鱼的第二大养殖鱼类，而吉富罗非鱼在其中占有很大比例。

◆ 在不损害其生长的情况下，可以忍受碳水化合物的水平高达 41%，但其具体的机制还不清楚。(Wu et al., 2012)

◆ 基因组的序列已知，是研究杂食性物种分子营养机制的理想对象。

1 研究背景

研究目的

实际饮食中淀粉与蛋白质的比例对GIFT罗非鱼生长和外周葡萄糖转运及利用的影响。

研究意义

这项研究的结果将有助于深入了解杂食性鱼类有效利用碳水化合物的分子机制。

2

实验方法

2 实验方法

Table 1

Formulation and proximate composition of the experimental diets.

Diets	LSP	MSP	HSP
Fish meal[a]	2.5	2	1.5
Soybean meal	30	25	20
Cottonseed meal	25	20	15
Rapeseed meal	17.5	15	12.5
小麦粉 Wheat flour	18.8	31.8	44.8
Soybean oil	2	2	2
Soybean lecithin	1	1	1
Monocalcium phosphate	2	2	2
Vitamin and mineral premix[b]	1	1	1
Choline chloride	0.2	0.2	0.2
Total	100	100	100
Analyzed composition (% dry matter)			
Dry matter	89.6	86.2	88.3
Crude protein	38.2	34.5	30.5
Crude lipid	5.49	5.55	5.59
Starch	13.1	22.5	32.3
Crude fiber	7.01	6.12	5.18
Ash	8.76	8.08	7.35

2 实验方法

体重为 23.0±0.1g 的吉富罗非鱼

LSP
13.1%淀粉和38.2%蛋白质

20 fishes | 20 fishes
20 fishes | 20 fishes

MSP
22.5%淀粉和34.5%蛋白质

20 fishes | 20 fishes
20 fishes | 20 fishes

HSP
32.3%的淀粉和30.5%的蛋白质

20 fishes | 20 fishes
20 fishes | 20 fishes

投喂12周后，禁食24h

每桶取6条

- 体成分（3条）
- 血液和生长指标
- 肝糖原含量
- 腹脂
- 肝脏和肌肉营养成分
- 糖脂代谢指标（酶活和基因）

取材剩下的每组鱼

- 腹腔注射1 g/kg BW葡萄糖
- 0、2、4、6、8、10h后取血液测定血糖水平

3 结果与讨论

3 结果与讨论

饲养期间罗非鱼的体重变化

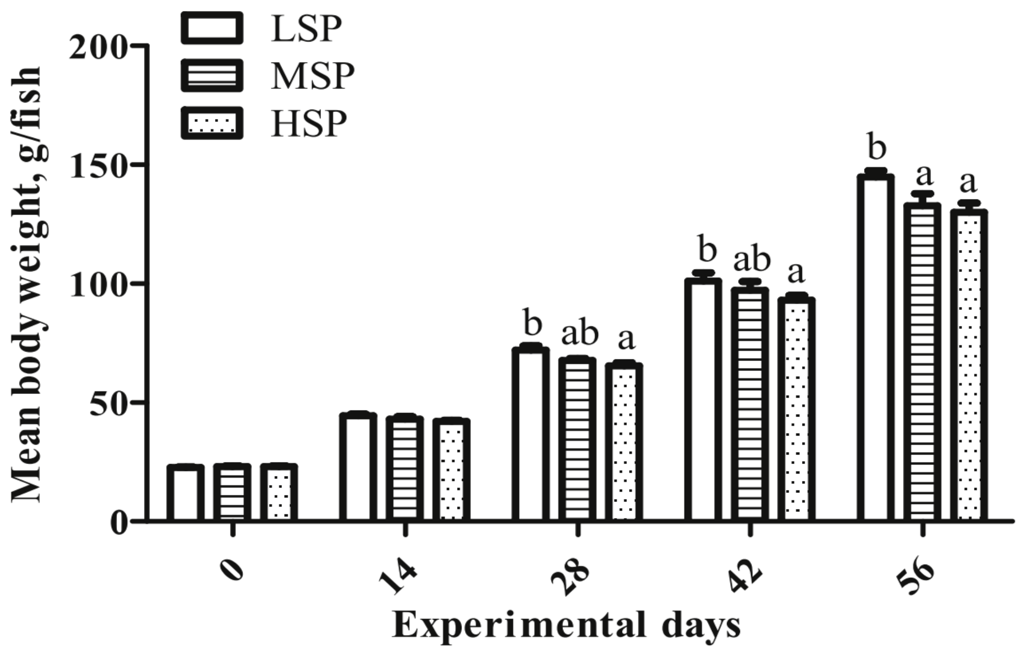


Fig. 1. Growth trajectory of tilapia during the feeding trial. Data are expressed as means ± SEM (n = 4). Different letters indicate significant differences among treatments at the same sampling time. LSP, 13.1% starch and 38.2% protein; MSP, 22.5% starch and 34.5% protein; HSP, 32.3% starch and 30.5% protein.

饲喂淀粉/蛋白质比例较高的日粮，会引起罗非鱼的生长发育迟缓。

3 结果与讨论

Table 2

Feed utilization and biometric parameters of tilapia fed experimental diets for 8 weeks.

	Diets	LSP	MSP	HSP
饲料系数	Feed efficiency ratio	0.99 ± 0.01^{ab}	1.02 ± 0.02^{b} ↑	0.96 ± 0.01^{a}
摄食量	Feed intake (g/fish)	124 ± 3^{b}	108 ± 4^{a} ↓	112 ± 4^{a} ↓
蛋白效率	Protein efficiency ratio	2.52 ± 0.01^{a}	2.87 ± 0.06^{b} ↑	3.04 ± 0.03^{c} ↑
蛋白质沉积率	Protein productive value (%)	41.7 ± 1.0^{a}	48.0 ± 0.9^{b} ↑	46.9 ± 0.4^{b} ↑
脂质沉积率	Lipid productive value (%)	142 ± 9^{a}	172 ± 5^{b} ↑	192 ± 9^{b} ↑
肥满度	Condition factor	3.80 ± 0.09^{b}	3.53 ± 0.11^{ab}	3.41 ± 0.09^{a} ↓
内脏指数	Viscerosomatic index (%)	8.74 ± 0.05^{a}	9.56 ± 0.27^{a}	11.37 ± 0.31^{b} ↑
肝脏指数	Hepatosomatic index (%)	2.45 ± 0.16^{a}	3.53 ± 0.16^{b} ↑	4.06 ± 0.10^{c} ↑
腹腔脂肪比	Intraperitoneal fat ratio (%)	0.54 ± 0.04^{a}	0.75 ± 0.08^{a}	1.13 ± 0.09^{b} ↑

Data are expressed as means ± SEM (n = 4). Different letters indicate significant differences among treatments. LSP, 13.1% starch and 38.2% protein; MSP, 22.5% starch and 34.5% protein; HSP, 32.3% starch and 30.5% protein.

3 结果与讨论

Table 3
Plasma biochemical indices of tilapia fed experimental diets for 8 weeks.

Diets	LSP	MSP	HSP
Glucose (mmol/L)	2.02 ± 0.09[a]	4.10 ± 0.18[b]	4.65 ± 0.32[b]
Triglyceride (mmol/L)	1.10 ± 0.09[a]	1.46 ± 0.23[a]	4.12 ± 0.18[b]
Cholesterol (mmol/L)	2.23 ± 0.13	2.15 ± 0.09	1.89 ± 0.17
Protein (g/L)	46.2 ± 0.6	46.8 ± 0.3	45.6 ± 0.2

Data are expressed as means ± SEM (n = 4). Different letters indicate significant differences among treatments. LSP, 13.1% starch and 38.2% protein; MSP, 22.5% starch and 34.5% protein; HSP, 32.3% starch and 30.5% protein.

3 结果与讨论

Table 4

Proximate composition in the whole-body, liver and white muscle of tilapia fed experimental diets for 8 weeks (% wet weight).

	Diets	Initial	LSP	MSP	HSP
	Whole-body moisture	81.1	73.7 ± 0.4^{b}	72.6 ± 0.3^{b}	71.8 ± 0.4^{a}
	Whole-body protein	11.4	15.8 ± 0.4^{b}	15.8 ± 0.1^{b}	14.7 ± 0.2^{a}
全鱼	Whole-body lipid	2.31	7.03 ± 0.41^{a}	8.17 ± 0.32^{a}	9.63 ± 0.47^{b}
	Whole-body ash	/	3.77 ± 0.20	3.82 ± 0.19	3.83 ± 0.18
	Liver moisture	/	73.2 ± 0.6^{b}	69.7 ± 1.3^{a}	68.8 ± 1.0^{a}
肝脏	Liver protein	/	9.72 ± 0.14^{b}	9.02 ± 0.41^{ab}	8.74 ± 0.21^{a}
	Liver lipid	/	5.74 ± 0.09^{a}	6.61 ± 0.25^{b}	9.19 ± 0.21^{c}
	Muscle moisture	/	78.5 ± 0.2	77.6 ± 1.0	78.9 ± 0.7
肌肉	Muscle protein	/	20.2 ± 0.3	20.4 ± 0.8	18.7 ± 0.5
	Muscle lipid	/	1.25 ± 0.10^{a}	1.48 ± 0.09^{ab}	1.81 ± 0.12^{b}

Data are expressed as means ± SEM (n = 4). Different letters indicate significant differences among treatments. LSP, 13.1% starch and 38.2% protein; MSP, 22.5% starch and 34.5% protein; HSP, 32.3% starch and 30.5% protein.

3

结果与讨论

肝脏与肌肉中的糖代谢酶活和糖原含量的变化

Table 5

Glycogen concentrations and glucose metabolic enzymatic activities in the liver and white muscle of tilapia fed experimental diets for 8 weeks.

Diets	LSP	MSP	HSP
Liver PFK activity (U/mg protein)	4.57 ± 0.43[a]	6.70 ± 0.53[b]	5.38 ± 0.45[ab]
Liver PCK activity (U/mg protein)	393 ± 12[b]	290 ± 17[a]	327 ± 8[a]
Liver glycogen (mg/g)	111 ± 4[a]	123 ± 3[a]	142 ± 3[b]
Muscle HK activity (U/g protein)	25.4 ± 1.1	25.7 ± 1.3	27.1 ± 1.2
Muscle PFK activity (U/mg protein)	80.1 ± 3.7[a]	105.6 ± 6.6[b]	109.8 ± 4.0[b]
Muscle glycogen (mg/g)	2.25 ± 0.11[a]	2.72 ± 0.15[a]	4.21 ± 0.17[b]

Data are expressed as means ± SEM (n = 4). Different letters indicate significant differences among treatments. PFK, phosphofructokinase; PCK, phosphoenolpyruvate carboxykinase; HK, hexokinase. LSP, 13.1% starch and 38.2% protein; MSP, 22.5% starch and 34.5% protein; HSP, 32.3% starch and 30.5% protein.

3 结果与讨论

肝脏中糖脂代谢相关基因表达量的变化

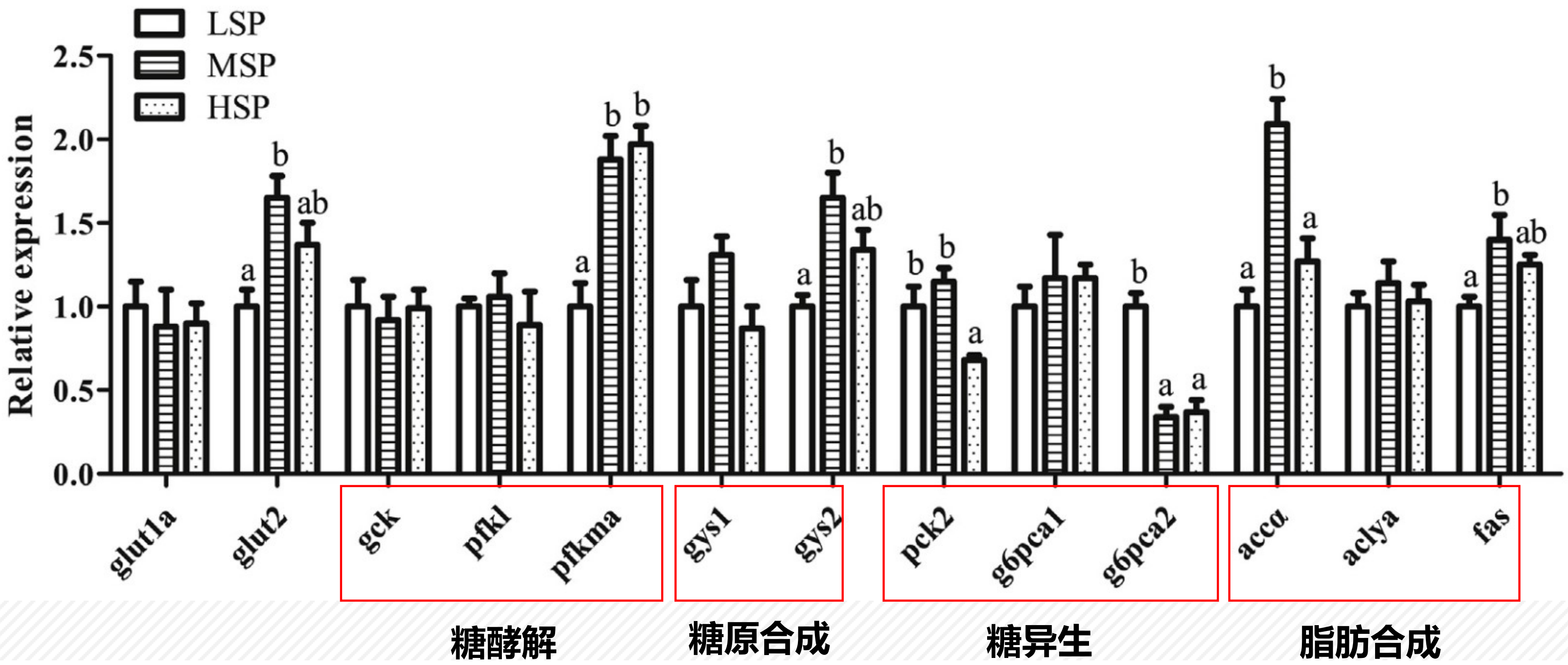


Fig. 3. Relative expression of genes involved with glucose transport and utilization in the liver of tilapia. Data are expressed as means ± SEM (n = 4). Different letters indicate significant differences among treatments. *glut*, glucose transporter; *gck*, glucokinase; *pfkl*, liver type of phosphofructokinase; *pfkm*, muscle type of phosphofructokinase; *gys*, glycogen synthase; *pck*, phosphoenolpyruvate carboxykinase; *g6pc*, glucose-6-phosphatase catalytic subunit; *acc*, acetyl-CoA carboxylase; *acly*, ATP citrate lyase; *fas*, fatty acid synthase. LSP, 13.1% starch and 38.2% protein; MSP, 22.5% starch and 34.5% protein; HSP, 32.3% starch and 30.5% protein.

这表明，饲喂高水平淀粉饲料，在罗非鱼的肝脏中，可以对糖类进行有效利用，并可以转化为糖原和脂质进行储存。

3 结果与讨论

肌肉中糖脂代谢相关基因表达量的变化

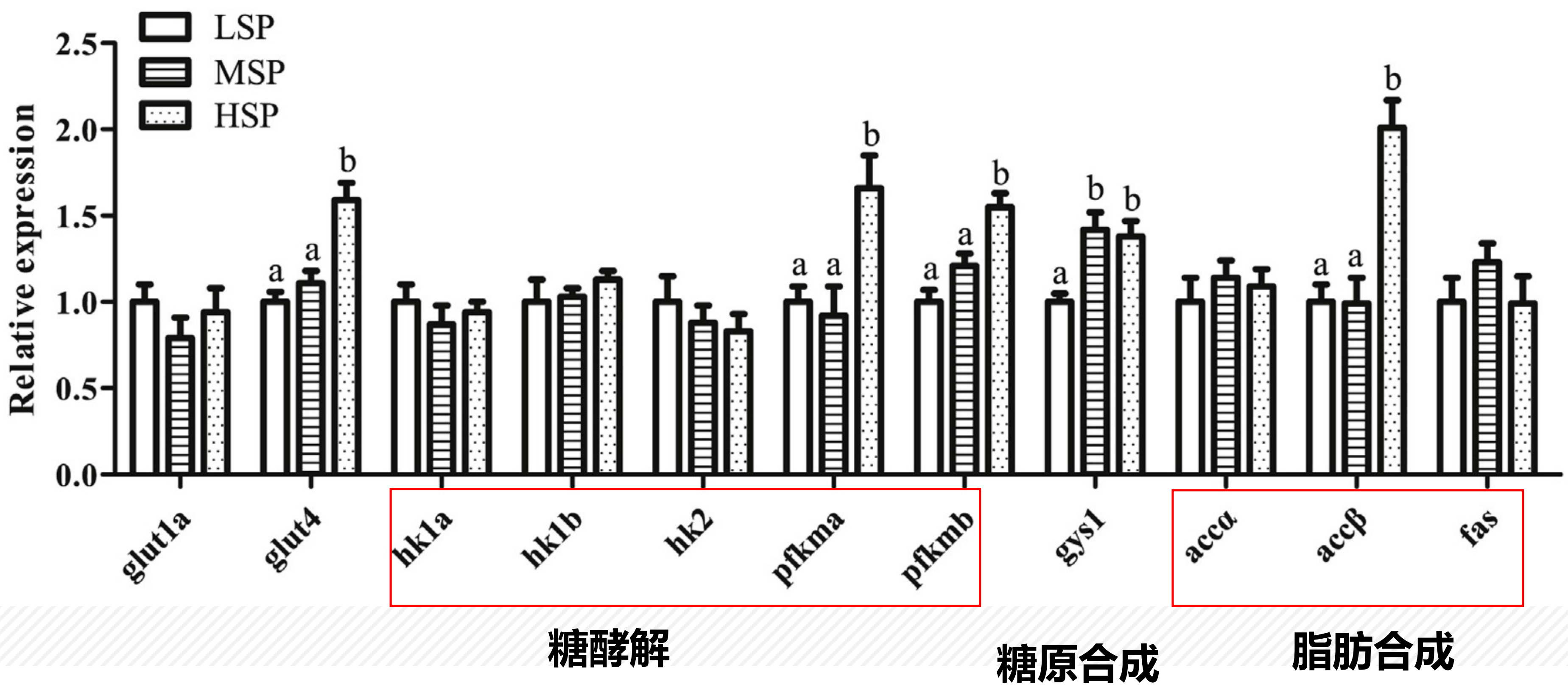
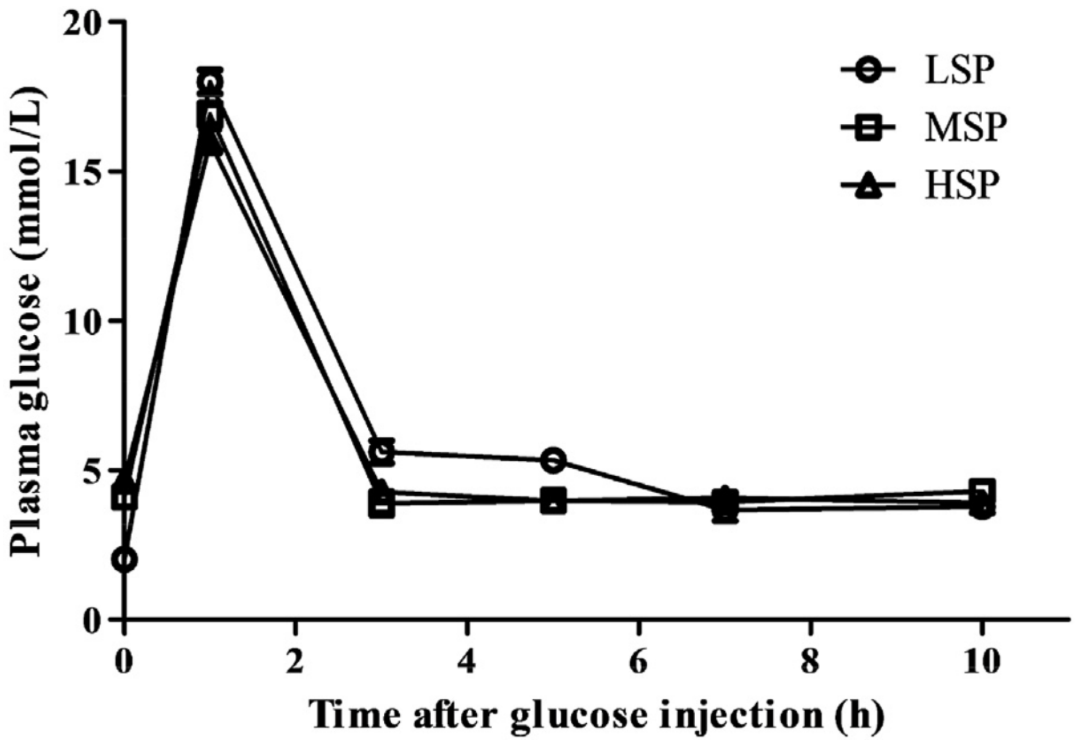


Fig. 4. Relative expression of genes involved with glucose transport and utilization in the white muscle of tilapia. Data are expressed as means ± SEM (n = 4). Different letters indicate significant differences among treatments. *glut*, glucose transporter; *hk*, hexokinase; *pfkm*, muscle type of phosphofructokinase; *gys*, glycogen synthase; *acc*, acetyl-CoA carboxylase; *fas*, fatty acid synthase. LSP, 13.1% starch and 38.2% protein; MSP, 22.5% starch and 34.5% protein; HSP, 32.3% starch and 30.5% protein.

在肌肉中，罗非鱼将多余的葡萄糖转化为糖原和脂质进行储存，这再次说明了该物种对碳水化合物的有效利用。

3 结果与讨论



	Hours (h)					
	0	1	3	5	7	10
LSP	Aa	Bd	Bc	Bc	b	b
MSP	Ba	ABb	Aa	Aa	a	a
HSP	Ba	Ab	Aa	Aa	a	a

Fig. 2. Changes in plasma glucose level of tilapia after a glucose load. Data are expressed as means ± SEM (n = 6). Lower-case letters indicate significant differences with sampling time within each treatment. Upper-case letters indicate significant differences among treatments at the same sampling time. LSP, 13.1% starch and 38.2% protein; MSP, 22.5% starch and 34.5% protein; HSP, 32.3% starch and 30.5% protein.

- 结果表明，在罗非鱼中，淀粉水平升高的饮食可以改善葡萄糖耐量。
- 是否会因为罗非鱼的膳食淀粉水平升高且持续时间延长，造成血浆葡萄糖继续增加?
- 因此，需要一个完整的生长周期试验来进一步确定高淀粉摄入量对罗非鱼外周葡萄糖利用和葡萄糖耐量的长期影响。

4 结论

综合上述结果：GIFT罗非鱼幼鱼通过促进周围葡萄糖的储存和利用，在代谢上很好地适应了淀粉水平从13.1％到32.3％的饮食，虽然增加了淀粉的摄入量会导致生长减慢，但可以提高葡萄糖耐量并改善蛋白质的保留能力。

敬请各位老师同学批评指正！

报告人：赵文丽

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